Maintaining Productive Efficiency of Solar Arrays

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Intro/Background

With the onset of climate change people are demanding better business behavior. As a result, many companies seek to diversify their public presence by acquiring technologies and behaviors that ultimately strive toward a goal of reducing environmental impacts. One particular focus of this transition has been the acquisition of clean energy technology. Solar photovoltaic arrays are one such technology that companies and homeowners continue to adopt to meet their environmental goals whether those goals are specific, measureable, impactful or whether they are more for self satisfaction and peace of mind. Administration and the Office for Sustainability at University of Richmond has set aggressive goals, promising reduce greenhouse gas emissions by 30 percent from 2009 levels by 2020 and to be carbon neutral by 2050.

To help meet these goals, the University has entered into agreement with a solar energy provider name SPower. They have proposed the construction of 500 MW of solar capacity In Spotsylvania county, making agreement with other companies like Microsoft and Apple who seek to offset the carbon footprint of their data centers. An array of this size has stirred up much controversy over environmental health, land rights, and resource use. Many have sought to weigh the costs and benefits of such an operation. One way to analyze a project of this size is to compare it to alternative solar strategies, namely residential rooftop arrays.

When considering large, environmentally impactful projects it is necessary to assess alternatives. One scale that might be a good fit for the University of Richmond in place of the purchase agreement with Spower is a community rooftop solar program. There are many criteria which allow for the comparison of potential solar projects such as proximity to consumer, ecological impact or public receptiveness. The criteria under evaluation in this study is power production performance. As a result of differing maintenance behaviors such as cleaning, solar panels in rooftop arrays produce on average, less electricity than utility arrays. Below I compare the space-use efficiency of the typical rooftop array to the space-use efficiency of a utility array to show that, given certain maintenance norms, one type of array produces more power per unit of area than the other. I performed a literature investigation of government documents, presentations, and scientific journal articles to base these conclusions.

Research has shown that photovoltaic arrays typically have a 25 year lifetime (DOE, n.d.) Upfront solar array costs are high and panel materials are costly and carbon intensive extract and recycle; there is great incentive to demonstrate and exceed this lifetime if possible (Haney, 2013.) Maximizing the performance of a solar array can mean a huge monetary difference both in terms of energy production and total lifetime use. One way of ensuring that a solar module performs properly and at peak efficiency is to simply make sure they stay clean.

For this research I seek to show that rooftop solar has different space-use-efficiency than utility arrays due to different maintenance behaviors surrounding panel soiling. Therefore, rooftop solar has comparatively different implications for meeting University of Richmond's sustainability commitments.

Methods

After being tasked with an analysis of solar scale I chose to approach the investigation within a framework of power performance and space-use. After researching different solar array scales it became apparent that soiling had a big impact on solar panel performance. I researched the causes of soiling and shading as well as the performance and cost implications

I reviewed various experiments that looked at PV power-losses under different shading and soiling circumstances. A few of these primary sources provided measurements of power output and voltage as a function of severity of soiling and hence the severity of shading. After reviewing these experiments I extracted measurements to create a graph showing the relationship between shading and power output as seen in the accompanying presentation graphic.

For the next step of analysis I reviewed several operations and maintenance plans for solar arrays and I pinpoint differences in behavior which may affect soiling of a solar module throughout the year. Among those differing behaviors is cleaning. Utility arrays and rooftop arrays have different cleaning requirements and accessibility implications (DOE, n.d.)

Finally I performed a literature review of the cost implications of cleaning behavior. Pulling information from both government documents and scientific journal articles allowed for the completion of the accompanying graphic showing the relationship between maintenance frequency, cost and power performance also seen in the accompanying presentation graphic.

Solar Operations and Maintenance contracts

Operations and maintenance(O&M) contracts lay out the standard operating procedures for a solar maintenance team. These contracts are generally negotiated before an array is installed and they determine how much technicians will be paid, how frequently they will come, what they will check and how they can fix mechanical and environmental problems (U.S., 2017). The main objective of O&M is system uptime. That is, the amount of time the system is operational and can produce electricity by converting incident sun rays. It can be difficult to tell how clean a solar panel might be at any given time, especially for modules placed on rooftops. Therefore it is important to be able to schedule regular maintenance checkups and cleanings as opposed to cleaning at will. This behavior characterizes what is known as preventative maintenance. Additionally, reactive maintenance becomes a necessity when events such as storms happen. These events may leave behind material such as snow or sand in addition to destabilizing the array entirely (DOE, n.d.)

Soiling Pollutants

Solar panels are subject to a number of environmental conditions depending on where they are located. These conditions can cause materials to accumulate on panel surfaces. In arid regions like the southwest United States and southern California, typical soiling pollutants are dust, bird droppings and sediment buildup after rainfall evaporates. Regions like Virginia have different implications for solar panel cleaning. From one standpoint one could say that there is less cleaning needed because the climate is moist and rain will take care of most of the debris that builds up on solar panel faceplates. We cannot however rely on precipitation to do the work for us. In northern regions precipitation can act as a soiling pollutant. During the winter, snow can buildup on solar panel and although snow is simply frozen rain, it blocks sunlight from reaching the inner components of the panel. Here in Virginia pollen is a particular concern. During spring pollen collects on just about any surface especially if the humidity percentage is very high (Darwish 2015; Deline 2010.)

One study looked at two solar arrays over a period of 4 months. One of the arrays was cleaned regularly while the other was left to the element. Overall, the neglected array demonstrated power outputs 4.2 percent lower than that of the maintained array (Sarver, 2013.)

Because we cannot rely on precipitation like rain to come by once a week and clean solar arrays we must establish some sort of cleaning maintenance plan to keep the panels clean and producing electricity at max output. When thinking about operations and maintenance plans there are generally two methods that contribute to panel cleanliness. The first type of maintenance we will look at is preventative maintenance and the second is reactive maintenance.

Preventative Maintenance

Preventative maintenance can be done with varying frequency. For instance, a utility array may decide to survey and clean their panels once a month. Rooftop arrays as a whole receive even less frequent inspections and as a result, fall victim to soiling, shading and voltage mismatch issues. This type of maintenance happens periodically (Haney, 2013.)

In addition to manufacturer specified maintenance, as per the solar module warranty, technicians typically check for corrosion, debris, structural stability, water buildup, loose connections, battery issues, cracked surfaces and also test the voltage and current of the module. They also make sure the tracking system functions, allowing the panel to switch position while maintaining any software associated with the array. Generally, two people are required for a thorough array inspection and adjustment (Haney, 2013.) These people must be technically qualified to perform these assessments because of the intricacy of the system build as well as the electrical hazards to which one may expose oneself (DOE, n.d.)

One of most important things that these technicians do is clean the panels and apply special coatings that guard against dust and other depositing materials. Soiling can be caused by dirt, pollen, snow, soot, humidity, salty air, or even bird droppings. As a result of the accumulation of these various substances, incident light from the Sun is blocked partially or throughout the entire panel module. Ultimately, soiling causes power output and voltage losses in solar panels depending on the severity of material buildup. These losses are said to be a result of “shading,” the term used to describe an obstruction of light, whether it is frozen water, flower pollen, sooty industrial emissions, or simply the shadow of a tree branch.

Unfortunately, shading can take on a multiplier effect even if the module isn’t entirely obstructed. This creates what is known as a voltage mismatch. Mismatches occur when an individual photovoltaic cell is inhibited the entire module might experience downtime because the voltage gets distributed across the shaded or damaged solar cells(U.S., 2017).

What makes this difficult is that the typical homeowner doesn't have the required expertise to check that the panels are performing correctly and even if they tried to clean the panels themselves, it would be dangerous, and photovoltaic cells have specific cleansing requirements. They must be washed with deionized water and scrubbed(if needed) with special brushes that won't harm the PV cell surface. Simply too much water pressure is enough to to harm panel functioning; maintenance, even cleaning should be done by solar technicians (DOE, n.d.**)**

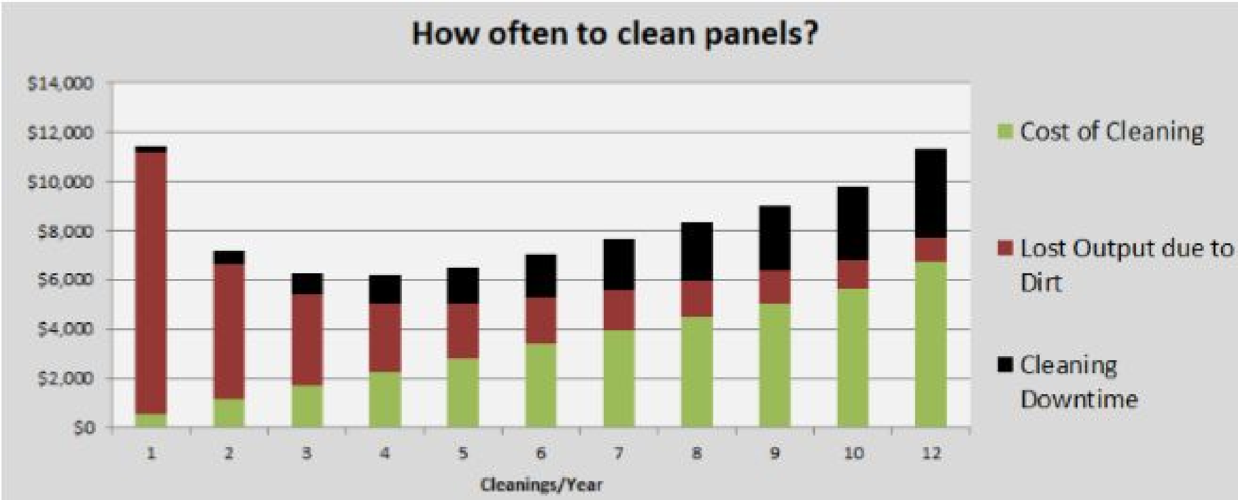
Reactive Maintenance

Reactive maintenance becomes necessary when an environmental event or equipment failure inhibits a solar module's ability to convert sunlight into electrical energy. This can happen quite often and unfortunately even small events can keep the entirety of the solar module from working. Mismatching is a particular concern because one shadowed panel can prevent the whole array from working properly. Unless the array is fitted with bypass diodes, voltage mismatches stemming from shaded cells can result in power output loss (Haney, 2013.)

Reactive maintenance within the framework of this research is best characterized as manual cleaning. This might look similar to preventative maintenance cleaning, but it is typically done at will when an array owner decides that the panels are too dirty or after an "event" has happened. Events can range from a flock of birds flying over head to a springtime release of pollen. Reactive maintenance can be more intensive than routine preventative maintenance because of the implied amount of time in between cleanings. There is more time for residues such as caked sand, bird droppings and distillates to build up on the panel surface and solidify. As a result, the cleaning chemicals and physical implements required must be more intense than what is used for preventative maintenance. (Maghami, 2016; Mani, 2010)

Maintenance Frequency

Utility Scale Arrays cleaning frequency	(Jiang, 2016)
Cleaning Interval	**Sources**
2 months	Nimmo and Said (1981)
14 months	Al-Busairi and Al-Kandari (1987)
12 months	Salim et al. (1988)
20 days	Cabanillas and Munguia (2011)
18 days	Hanai et al. (2011)



(Haney, 2013)

After reviewing the cleaning strategies of different solar arrays it is apparent that there is great variation in regular cleaning intervals due to differences in the surrounding environment, size of the array, and type of panels being used. It is important to note that different cleaning frequencies have different cost implications as seen in the graphic above. According to this particular study done by Haney, costs can be minimized if cleanings are done 4 times per year. More than 4 times per years brings higher amounts of array downtime while anything less than 4 cleanings per year significantly increases the amount of power output that is lost due to soiling (Haney, 2013.)

Discussion

On the one hand, envision an electric utility provider that wants to diversify its portfolio by investing in green energy. It is in the company's best interests to keep the panel running at peak efficiency both to ensure panel longevity, cost-effective renewable energy, and a positive public appearance. In general company boards of supervisors will lay out an operations and maintenance plan, projecting the costs before the array has even been built. As a result, every third Tuesday, a specialized solar maintenance crew visits the entirety of the array to clean, check inverters, and troubleshoot any issues.

On the other hand, envision a homeowner who takes advantage of the cost savings a rooftop array might bring in the long run. He got caught up in a front door conversation with a solar canvasser notifying him of community solar subsidization programs and subsequently decided to purchase one of six different types of solar arrays for his home. The homeowner leaves in the morning for work and and comes home at the end of the day. He knows his new array is up on his roof producing power, but has no idea how much or to what degree of efficiency other than what he was told by the installers. In fact, other than when he actually sees the roof of his house or when he gets his energy bill, he doesn't even think about the array.

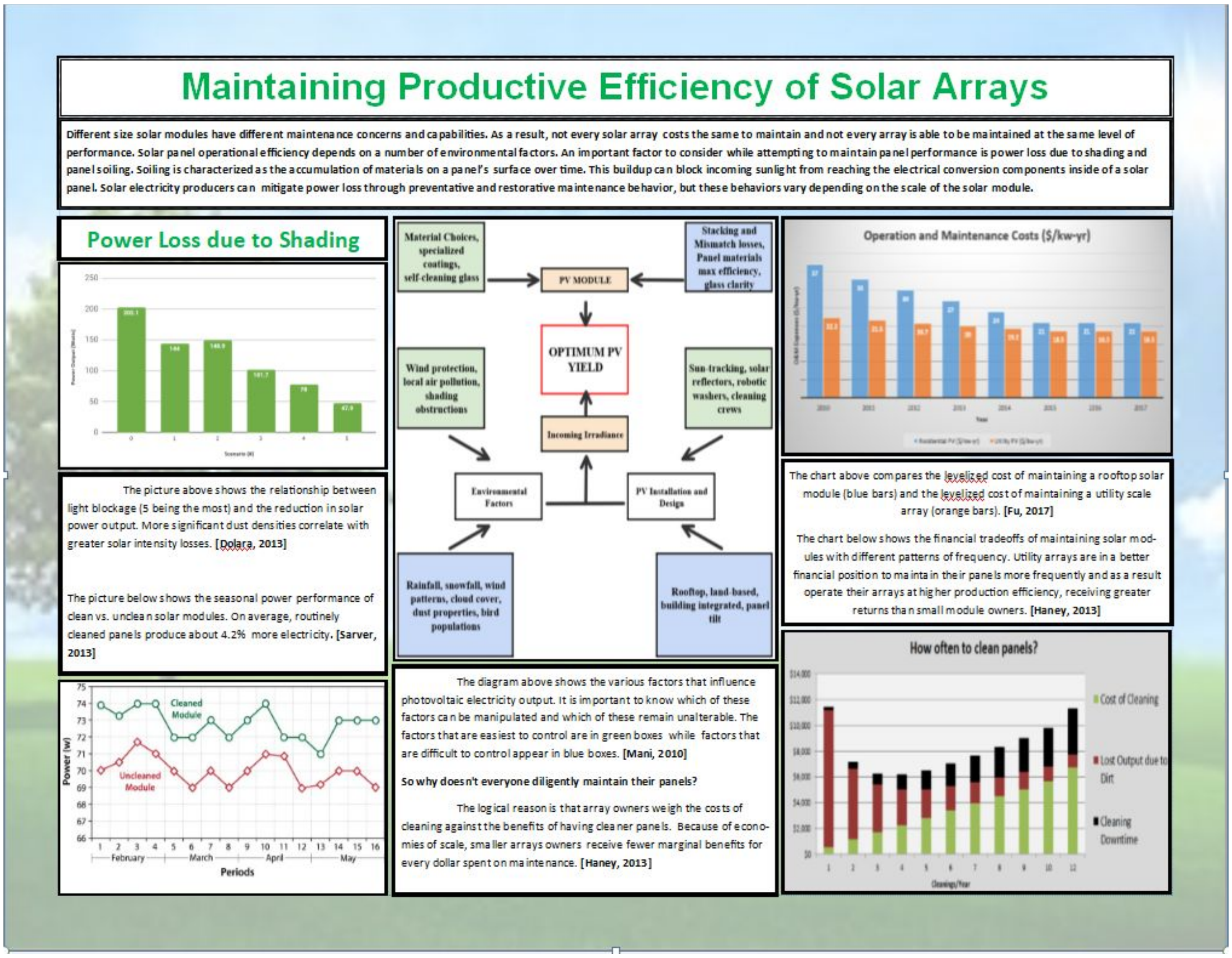
Indeed, a homeowner may hire a team to clean his array routinely, however this is more costly for a homeowner to do than it is for a corporation with many, many more panel. Because utility arrays have more panels, the benefits derived from hiring a cleaning team to remove soiling pollution periodically are much greater than for a homeowner with only 18 panels on his roof. It is therefore not cost effective for the homeowner to routinely clean his panels.

When considering the alternative to Spower's purchase agreement of investing in a residential rooftop program it is important to take the ineffectiveness into account. If it is not cost effective for an array owner to clean his panels it can be said that it won't happen very often. From an economist's standpoint, the price of cleaning is higher and as price rises, demand falls. I therefore establish that the panels in a rooftop solar program would be less clean on average than panels in a utility array and as a result produce less power per unit of surface area. From a power production and maintenance perspective, the purchase agreement with Spower is better than the alternative of investing in a residential rooftop solar program. Even if we were able to cover the same surface area with rooftop solar panels we wouldn't be able to produce as much electricity. Spower's panels will be cleaner, which will allow them produce more electricity per unit of surface area.

Overall, analyzing solar scale proved to be difficult because of the varying frameworks and directions from which to approach the issue of scale. There are quite a few holes in this research that could not be addressed due to time constraints. A local analysis of solar arrays and their maintenance behaviors would serve well to evaluate the feasibility of a rooftop solar program compared to the purchase agreement with Spower. Interviews with local homeowners who have rooftop arrays would unearth a lot of information about residential solar cleaning behaviors. This information was lacking in the literature review.

Operations and maintenance contracts are complicated documents that are generally tailored to a specific operation. An analysis of various aspects of maintenance plans would be useful in comparing utility arrays with rooftop arrays. Another suggestion for further research of this topic would be to use an economic model to compare maintenance needs with maintenance costs.

The most useful analysis would be to set up experiments to test, first hand, what different environmental conditions will do to power output performance and how different cleaning frequencies will effect that output. This would require the help of a solar technician because working with a test array would be much different than an individual test solar cell. In addition to electrical safety, the technician could provide the information needed to extract and interpret data from a solar array.



Graphic writeup:

I chose to analyze solar scale from a power performance vs. maintenance cost perspective. This research adds to the pool of knowledge when weighing the alternatives of a solar power purchase agreement such as the one UR has with Spower. I chose to create a series of infographics to demonstrate problem of shading factors that affect power production performance. Since one cannot see what is going on inside of a solar panel, the data I have analyzed is presented graphically to present broad relationships between maintenance and power output. It is important to know which factors can be adjusted to maximize the performance of an array so that owners are better able to maximize their return on investment.

Utility and community-rooftop solar differ in that utility arrays have more financial backing and as a result achieve higher benefits from the money they spend on maintenance. In addition, greater panel homogeneity in the utility arrays decreases the cost and complexity of performing regular cleaning maintenance. Robotic pressure washers and advance cleaning chemicals can be cost prohibitive for small solar modules.

One can infer from these assertions that community rooftop arrays are more costly to maintain and therefore are maintained less frequently than utility arrays. In this case a community rooftop scale array is not more conducive to reaching University of Richmond's sustainability goals than a utility array. Even if we could occupy the same surface area with smaller solar modules, maintenance would be costly and as a result, power efficiency would be lower than in well-kept utility arrays. From this standpoint utility arrays produce more electricity per unit of surface area and therefore are a better match for University of Richmond's current sustainability commitments.

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